

1    I CLAIM:

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3                    1.    Endothermic catalytic reaction apparatus  
4    comprising:

5                    a)    a U-shaped flow through tubular reaction  
6    chamber disposed upright within a combustion chamber,  
7    and a catalyst contained within said reaction chamber  
8    for the conversion of hydrocarbon to industrial gases  
9    by reaction with steam; said reaction chamber having an  
10   upper portion, and there being a convection chamber  
11   extending about said upper portion to enhance the  
12   transfer of heat from combustion products in the  
13   reaction chamber, and

14                   b)    a radiant burner generally vertically  
15   disposed within the combustion chamber and having a gas  
16   permeable zone that promotes the flameless combustion  
17   of fuel and oxidant supplied to said burner in order to  
18   heat a metal fiber surface of the burner to  
19   incandescence for radiating heat to the reaction  
20   chamber; said radiant burner configured so that the  
21   angle of radiation is predominantly incident upon the  
22   surface of the tubular reaction chamber.

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1           2.    The combination of claim 1 wherein said  
2   tubular reaction chamber comprises a tube having outer  
3   diameter or diameters ranging from about  $\frac{1}{4}$  inch to  
4   about 4 inches along the tube length.

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7           3.    The combination of claim 1 wherein said  
8   tubular reaction chamber is sized for creation of mass  
9   velocities ranging from 400 lb/ft<sup>2</sup>/h to 1500 lb/ft<sup>2</sup>/h.

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12           4.    The combination of claim 1 wherein said  
13   catalyst in the tubular reaction chamber has average  
14   catalyst particle diameters ranging from 1/8 to 1 inch  
15   for producing gas pressure drops ranging from 1 psi to  
16   8 psi during flow through the reaction chamber.

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19           5.    The combination of claim 1 wherein said  
20   tubular reaction chamber has a gas exit end temperature  
21   ranging from 1150°F to 1400°F when heated by said  
22   radiant burner, in operation.

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1           6.    The combination of claim 1 wherein said  
2   tubular reaction chamber has legs and an arc-shaped  
3   bend connecting said legs, and said legs and bend have  
4   maximum tube wall temperatures ranging from 1300°F to  
5   1600°F when heated by said radiant burner, in  
6   operation.

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9           7.    The combination of claim 1 wherein said  
10   tubular reaction has average heat fluxes ranging from  
11   3,000 btu/ft<sup>2</sup>/h to 10,000 btu/ft<sup>2</sup>/h, when heated by  
12   said radiant burner in operation.

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15           8.    The combination of claim 1 wherein said  
16   tubular reaction chamber is sized to have capacity to  
17   generate hydrogen plus carbon monoxide product in  
18   volumetric quantities ranging from 50 SCFH to between  
19   500 and 1500 SCFH.

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22           9.    The combination of claim 1 wherein said  
23   radiant burner comprises a supported porous ceramic  
24   material having extended life at operating temperatures  
25   up to 2100°F.

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1           10. The combination of claim 1 wherein said  
2 radiant burner comprises a supported metal fiber  
3 material consisting essentially of an alloy containing  
4 principally iron, chromium, and aluminum and smaller  
5 quantities of yttrium, silicon, and manganese, said  
6 alloy having extended life at operating temperatures up  
7 to 2000°F.

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10           11. The combination of claim 1 wherein said  
11 radiant burner is configured to direct radiation at an  
12 included angle of radiation between 45-180 degrees.

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15           12. The combination of claim 1 wherein said  
16 radiant burner has a hemispherical shape.

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19           13. The combination of claim 1 wherein said  
20 radiant burner has surface temperatures ranging from  
21 1500°F to 1900°F, in operation.

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1           14. The combination of claim 1 wherein said  
2 radiant burner has an operating combustion intensity  
3 typically ranging from 150,000 btu/ft<sup>2</sup>/h to  
4 350,000 btu/ft<sup>2</sup>/h, wherein the combustion intensity is  
5 defined as the higher heating value of the fuel  
6 combusted divided by the permeable radiant burner  
7 surface area.

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10           15. The combination of claim 1 wherein said  
11 radiant burner has an operating excess air ratio  
12 typically ranging from 30% to 100%, wherein the excess  
13 air ratio is defined as percent combustion air in  
14 excess of the stoichiometric amount required for  
15 complete combustion of the burner fuel.

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1            16. Endothermic catalytic reaction  
2 apparatus, comprising  
3            a) a combustion chamber,  
4            b) a tubular reaction chamber having two  
5 generally tubular legs extending in generally parallel,  
6 spaced apart relation within the combustion chamber,  
7            c) catalyst within said reaction chamber  
8 for reacting with a hydrocarbon and steam received  
9 within the reactor chamber, to produce hydrogen and  
10 carbon dioxide,  
11            d) a generally tubular radiant burner  
12 within the combustion chamber and extending in  
13 generally parallel relation to at least one of said  
14 legs, said burner spaced from said legs,  
15            e) said two legs having axes, and said  
16 tubular burner having an axis which is spaced in offset  
17 relation to a plane defined by said leg axes.

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20            17. The combination of claim 16 wherein said  
21 burner axis is approximately equidistant from said leg  
22 axes.

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1           18. The combination of claim 16 wherein said  
2 burner has heat radiating surfaces configured to  
3 radiate heat predominately in directions toward said  
4 legs.

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7           19. The combination of claim 16 wherein said  
8 legs are in series communication.

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11           20. The combination of claim 16 wherein the  
12 burner has a gas permeable metal fiber zone  $\gamma_1$ , and  
13 non-gas permeable zone  $\gamma_2$ , where  $\gamma_1$  faces said legs  
14 and  $\gamma_2$  faces away from said legs,  $\gamma_1$  subtending an  
15 angle that is less than 180°.

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1                   21. Endothermic catalytic reaction apparatus  
2 comprising:

3                   a) a helical tubular flow through reaction  
4 chamber disposed within a combustion chamber, and  
5 catalyst contained within said reaction chamber for the  
6 conversion of hydrocarbon to industrial gases by  
7 reaction with steam; said helical tubular reaction  
8 chamber having an upper portion, and there being a  
9 convection chamber extending about said upper portion  
10 to enhance the transfer of heat from combustion  
11 products in the reaction chamber and an exit section to  
12 convey reaction products to the exit means, and

13                   b) a radiant burner vertically disposed  
14 within said combustion chamber and having a gas  
15 permeable zone that promotes the flameless combustion  
16 of fuel and oxidant supplied to said burner in order to  
17 heat the metal fiber surface of the burner to  
18 incandescence for radiating heat energy to the reaction  
19 chamber; said radiant burner configured to radiate  
20 uniformly in radial directions.

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23                   22. The combination of claim 21 wherein said  
24 tubular reaction chamber comprises a tube having outer  
25 diameters ranging from about  $\frac{1}{8}$  inch to about 4 inches,  
26 along the tube length.



1           23. The combination of claim 21 wherein said  
2 tubular reaction chamber defines a coil having an outer  
3 coil diameter ranging from 6 to 36 inches.

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6           24. The combination of claim 21 wherein said  
7 helical tubular reaction chamber is for creation of  
8 mass velocities ranging from  
9 400 lb/ft<sup>2</sup>/h to 1500 lb/ft<sup>2</sup>/h.

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12           25. The combination of claim 21 wherein said  
13 catalyst in the helical tubular reaction chamber has  
14 average catalyst particle diameters ranging from ¼ to 1  
15 inch for producing gas pressure drops ranging from 1  
16 psi to 8 psi during flow through the reaction chamber.

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19           26. The combination of claim 21 wherein said  
20 helical tubular reaction chamber has gas exit end  
21 temperature ranging from 1150°F to 1400°F, when heated  
22 by said radiant burner, in operation.

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1           27. The combination of claim 21 wherein said  
2 helical tubular reaction chamber has maximum tube wall  
3 temperatures ranging from 1300°F to 1600°F, when heated  
4 by said radiant burner, in operation.

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7           28. The combination of claim 21 wherein said  
8 helical tubular reaction chamber has average heat  
9 fluxes ranging from 3,000 btu/ft<sup>2</sup>/h to  
10 10,000 btu/ft<sup>2</sup>/h, when heated by said radiant burner in  
11 operation.

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14           29. The combination of claim 21 wherein said  
15 helical tubular reaction chamber is sized to have  
16 capacity to generate hydrogen plus carbon monoxide  
17 product in volumetric quantities ranging from 50 SCFH  
18 to between 100 and 1500 SCFH.

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21           30. The combination of claim 21 wherein said  
22 radiant burner comprises a supported porous ceramic  
23 material having extended life at operating temperatures  
24 up to 2100°F.

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1           31. The combination of claim 21 wherein said  
2 radiant burner comprises a supported metal fiber  
3 material consisting essentially of an alloy containing  
4 principally iron, chromium, and aluminum and smaller  
5 quantities of yttrium, silicon, and manganese, said  
6 alloy having extended life at operating temperatures up  
7 to 2000°F.

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10           32. The combination of claim 21 wherein said  
11 radiant burner is configured to radiate heat energy in  
12 a substantially uniform radial pattern.

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15           33. The combination of claim 21 wherein said  
16 radiant burner has surface temperatures ranging between  
17 1500°F and 1900°F, in operation.

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20           34. The combination of claim 21 wherein said  
21 radiant burner has an operating combustion intensity  
22 typically ranging from 150,000 btu/ft<sup>2</sup>/h to  
23 350,000 btu/ft<sup>2</sup>/hr, wherein the combustion intensity is  
24 defined as the higher heating value of the fuel  
25 combusted divided by the permeable radiant burner  
26 surface area.

1           35. The combination of claim 21 wherein said  
2 radiant burner has an operating excess air ratio  
3 typically ranging from 30% to 100%, wherein the excess  
4 air ratio is defined as percent combustion air in  
5 excess of the stoichiometric amount required for  
6 complete combustion of the burner fuel.

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9           36. The combination of claim 22 wherein the  
10 coil has free area in the range 50% to 75%, wherein the  
11 free area is defined as the ratio of the free area  
12 between successive coil turns and the cylinder that  
13 bisects the helical coil circle.

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16           37. The combination of claim 21 wherein the  
17 convection chamber has an inlet within the combustion  
18 chamber, and an outlet outside the combustion chamber.

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21           38. The combination of claim 1 including a  
22 fuel cell in operating communication with said reaction  
23 chamber, to receive hydrogen therefrom.

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1                   39. The combination of claim 21 including a  
2 fuel cell in operating communication with said reaction  
3 chamber, to receive hydrogen therefrom.

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6                   40. The method of converting a hydrocarbon  
7 to industrial gases, that includes:

8                   a) providing a U-shaped flow through  
9 tubular reaction chamber disposed upright within a  
10 combustion chamber, and a catalyst contained within  
11 said reaction chamber for the conversion of said  
12 hydrocarbon to said industrial gases by reaction with  
13 steam; said reaction chamber having an upper portion,  
14 and there being a convection chamber extending about  
15 said upper portion to enhance the transfer of heat from  
16 combustion products in the reaction chamber,

17                   b) providing a radiant burner generally  
18 vertically disposed within the combustion chamber and  
19 having a gas permeable zone that promotes the flameless  
20 combustion of fuel and oxidant supplied to said burner  
21 in order to heat a fiber surface of the burner to  
22 incandescence for radiating heat to the reaction  
23 chamber; said radiant burner configured so that the  
24 angle of radiation is predominantly incident upon the  
25 surface of the tubular reaction chamber,

1           c)    supplying said hydrocarbon and steam to  
2 the reaction chamber heated by said radiant burner,  
3           d)    and removing said industrial gases  
4 including hydrogen from the reaction chamber.

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7           41. The method of claim 40 including  
8 providing a gas conditioning system and fuel cell, and  
9 supplying said hydrogen to said fuel cell.

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12           42. The method of claim 40 wherein said  
13 fiber surface of the burner consists of at least one of  
14 the following:

15           a)    ceramic

16           b)    metal.

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1                   43. Endothermic catalytic reaction apparatus  
2   that includes a combustion chamber, comprising:  
3                   a)   a straight tubular outer conduit  
4   concentrically disposed around an inner conduit to form  
5   a reaction chamber containing catalyst in the annular  
6   space between the outer conduit wall and the inner  
7   conduit wall, for conversion of hydrocarbon to  
8   industrial gases by reaction with steam, and an inner  
9   conduit defined space for the return flow of reactant  
10   gases to an exit means; said tubular reaction chamber  
11   having one end that extends into the combustion chamber  
12   and an opposite end that extends outside of the  
13   combustion chamber, and there being inlet means that is  
14   in communication with the annular space and an exit  
15   means that is in communication with the inner conduit  
16   defined space,  
17                   b)   and a radiant burner vertically disposed  
18   within said combustion chamber and having a gas  
19   permeable zone that promotes the flameless combustion  
20   of fuel and oxidant supplied to said burner in order to  
21   heat the metal fiber surface of the burner to  
22   incandescence for radiating heat energy to the reaction  
23   chamber.  
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1           44. The combination of claim 43 wherein a  
2 multiplicity of said tubular reaction chambers are  
3 provided and are concentrically disposed around a  
4 centrally located and vertically disposed cylindrical  
5 radiant burner having a 360 degree radiant arc.  
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8           45. The combination of claim 43 wherein  
9 there is a convection chamber extending about a portion  
10 of the tubular reaction chamber in the proximity of the  
11 end containing the reactant gas inlet and outlet means  
12 to enhance heat transfer from combustion products; said  
13 convection chamber having an inlet means that is in  
14 communication with the combustion chamber and an exit  
15 means for combustion products that is outside the  
16 combustion chamber.  
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19           46. The combination of claim 43 wherein the  
20 reactant gases flowing inside the inner conduit  
21 transfer heat to the reaction chamber.  
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24           47. The combination of claim 43 wherein said  
25 radiant burner is comprised of a supported metal fiber  
26 material.



1                   48. The combination of claim 43 wherein said  
2 radiant burner is comprised of a supported ceramic  
3 fiber material.

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